

# Evaluation of an Empirical Binning Approach for Analyzing On-Board Emission Data for MOVES

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# Acknowledgements

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- Team members:
  - John Koupal
  - Robert Giannelli
  - David Brzezinski
  - James Warila
- Peter McClintock of Applied Analysis for suggesting the VSP binning approach

# Bin Concept

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- Completely data driven
- Produces emission rates based on data falling in a specific bin
- Applies to vehicle characteristics and vehicle operation

# Vehicle Specific Power (VSP)

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- Equation developed by Jimenez-Palacios (MIT) for light duty vehicles:

$$\text{VSP(kW/metric ton)} = v[1.1a + 9.81(\text{atan}(\sin(\text{grade}))) + 0.132] + 0.000302v^3$$

Where

v in m/s

a in m/s<sup>2</sup>

1.1 = coefficient of equivalent mass for rotating components

9.81 = acceleration of gravity (m/s<sup>2</sup>)

grade = vertical rise / horizontal distance (for small angles)

0.132 = rolling resistance coefficient

0.000302 = drag term coefficient

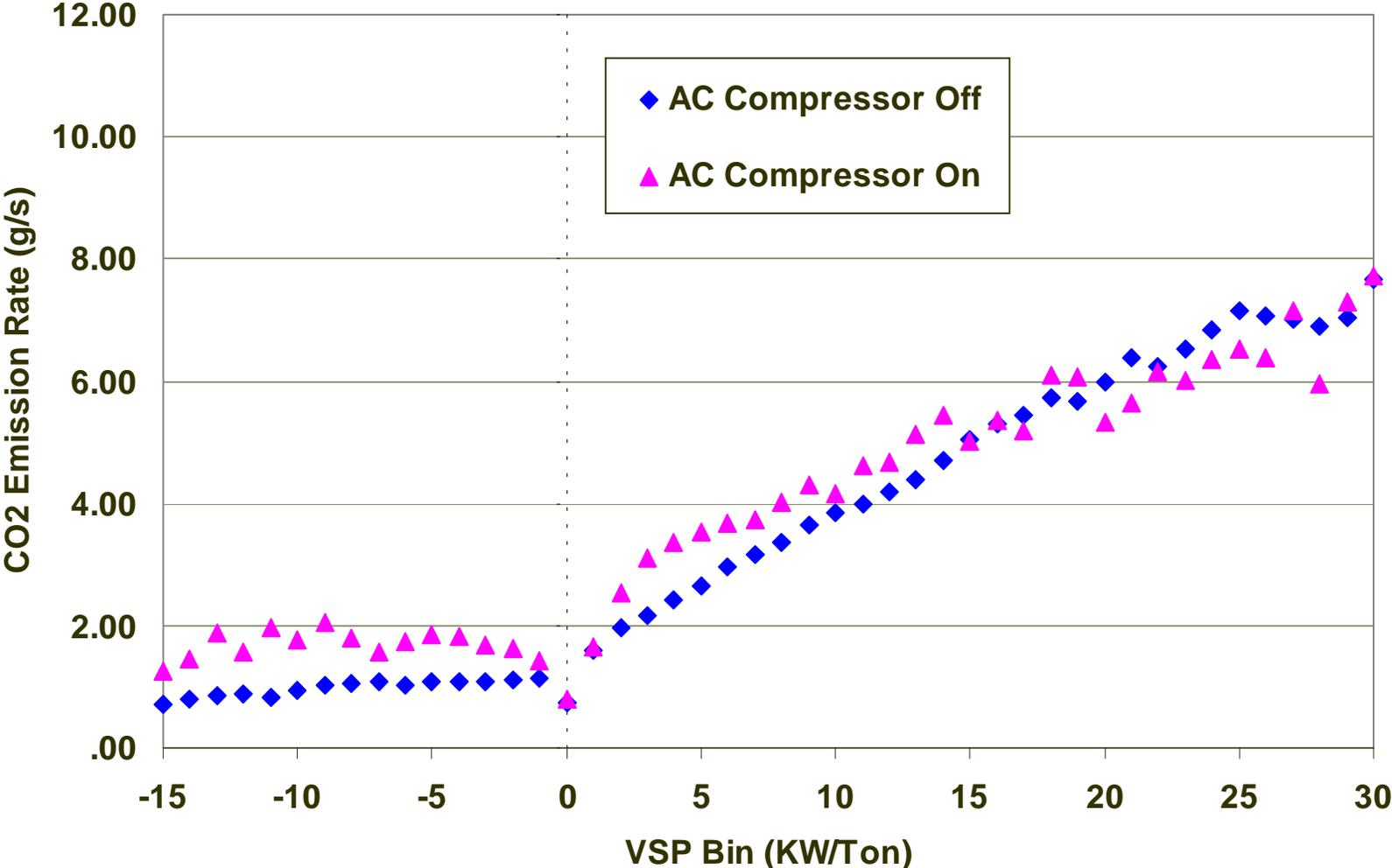
# Light-Duty Bin Determination

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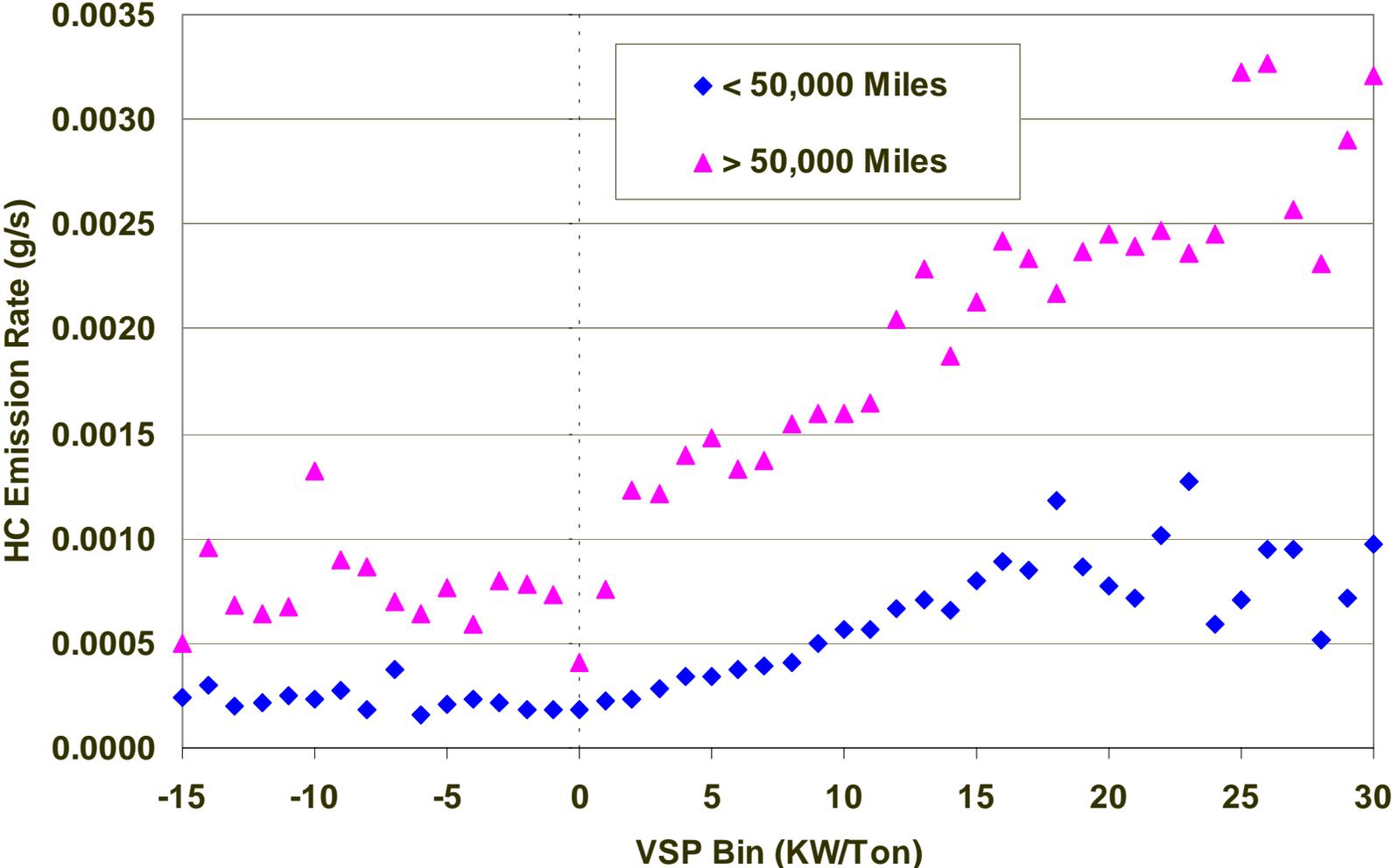
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- VSP: Increments of 1 kW/ton
  - -15 kW/ton to +30 kW/ton
- Additional Bin Parameters:
  - CO<sub>2</sub>:
    - Cylinders, AC On/Off
  - HC, CO, NO:
    - Start/Running, Cylinders, Mileage, Soak Time
- Emission rate = average of all values falling in a given bin

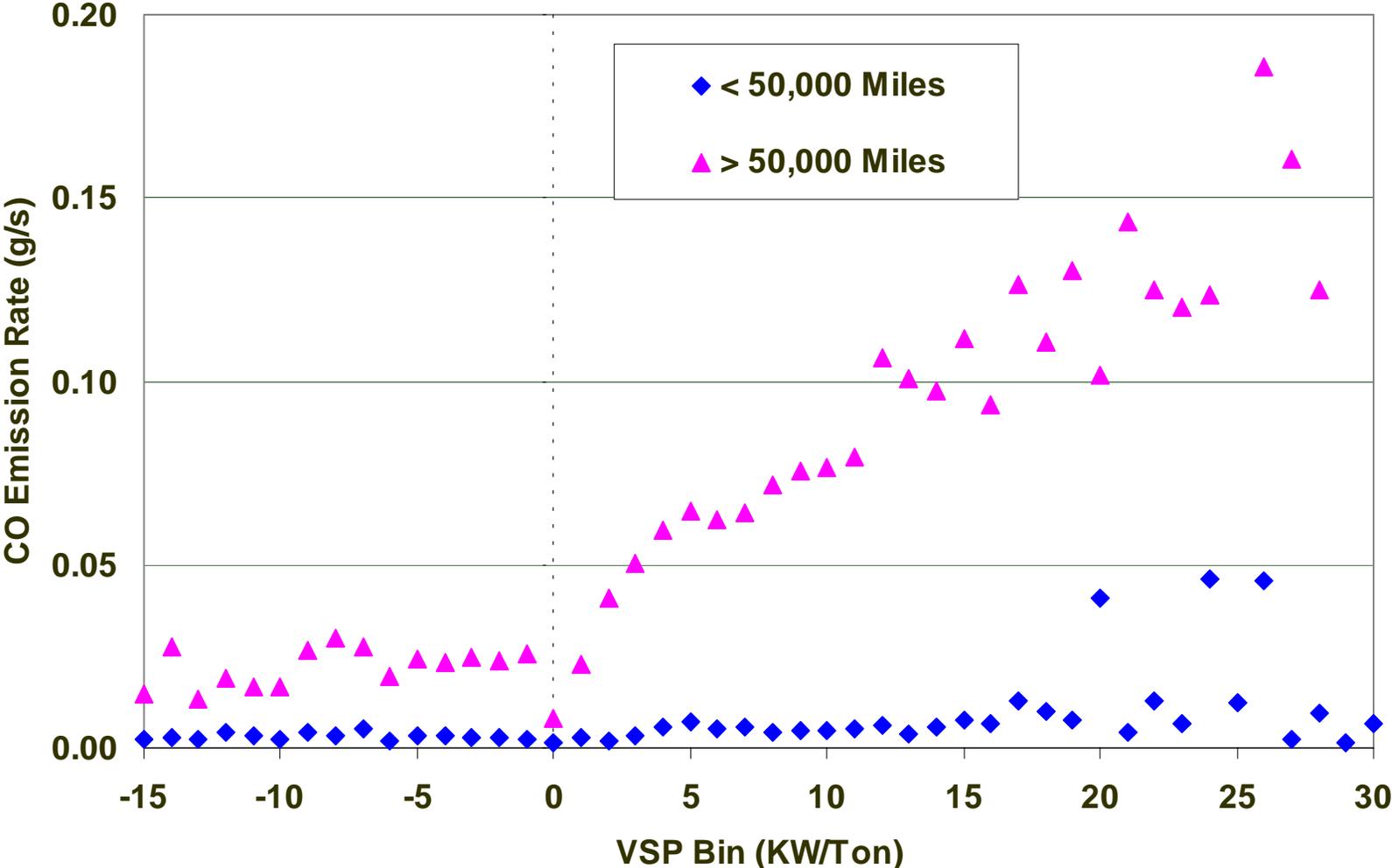
# CO2 Emission Rate By VSP Bin 4 Cylinder LDVs



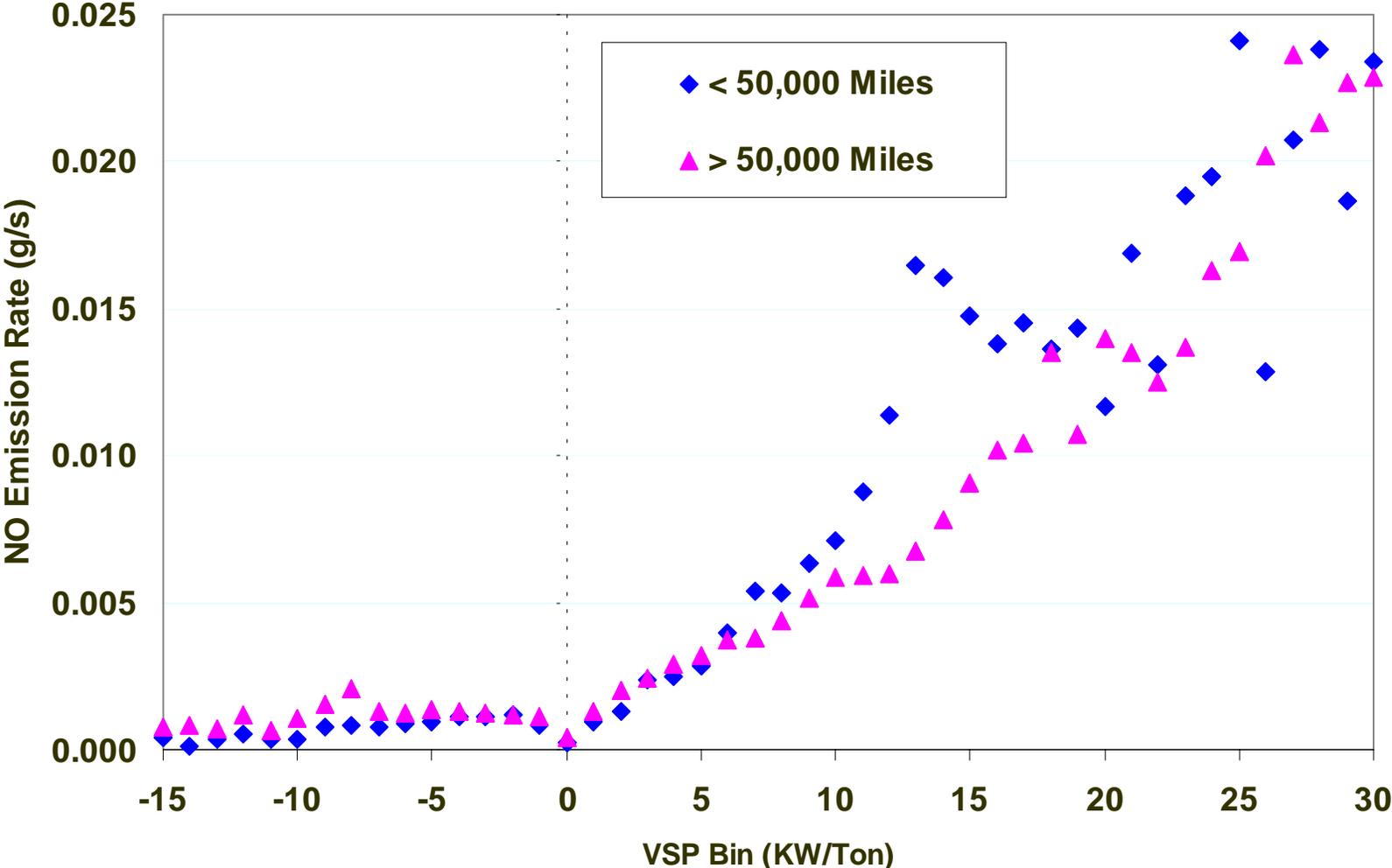
# Running HC Emission Rate By VSP Bin 4 Cylinder LDVs



# Running CO Emission Rate By VSP Bin 4 Cylinder LDVs



# Running NO Emission Rate By VSP Bin 4 Cylinder LDVs



# Bus Analysis

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- Simpler analysis
  - No starts
  - Little variation across vehicles
- Binned only VSP
- Emission rates = average of values falling in bin, by bus

# Bus VSP Equation

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## ■ Coefficients derived from Andrei (WVU):

$$\text{VSP(kW/metric ton)} = v[a + 9.81(\sin(\text{grade})) + 0.092] + 0.42v^2$$

Where

$v$  = velocity in m/s

$a$  = acceleration in  $\text{m/s}^2$

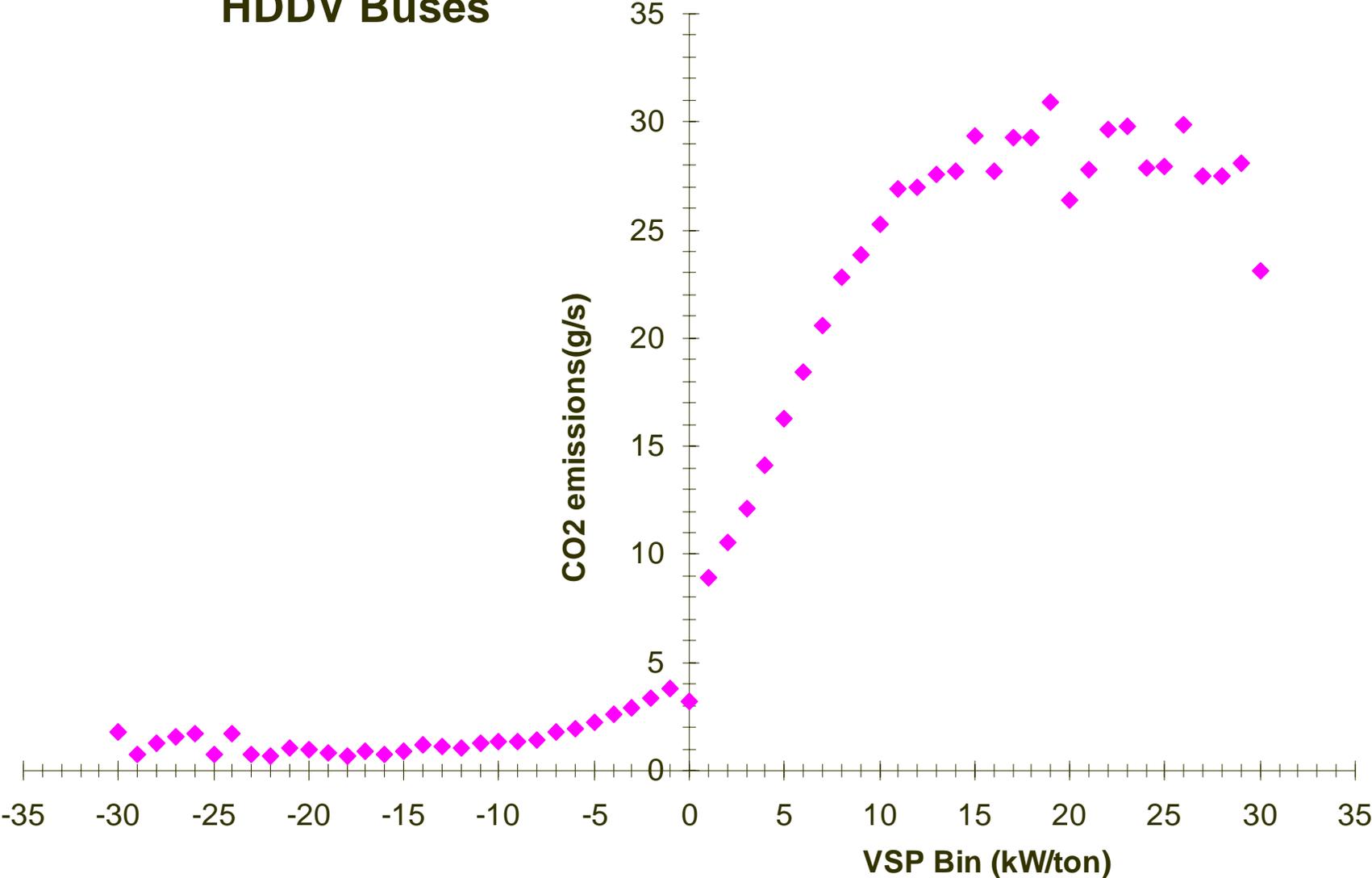
9.81 = acceleration of gravity ( $\text{m/s}^2$ )

grade = vertical rise / horizontal distance (for small angles)

0.092 = rolling resistance coefficient

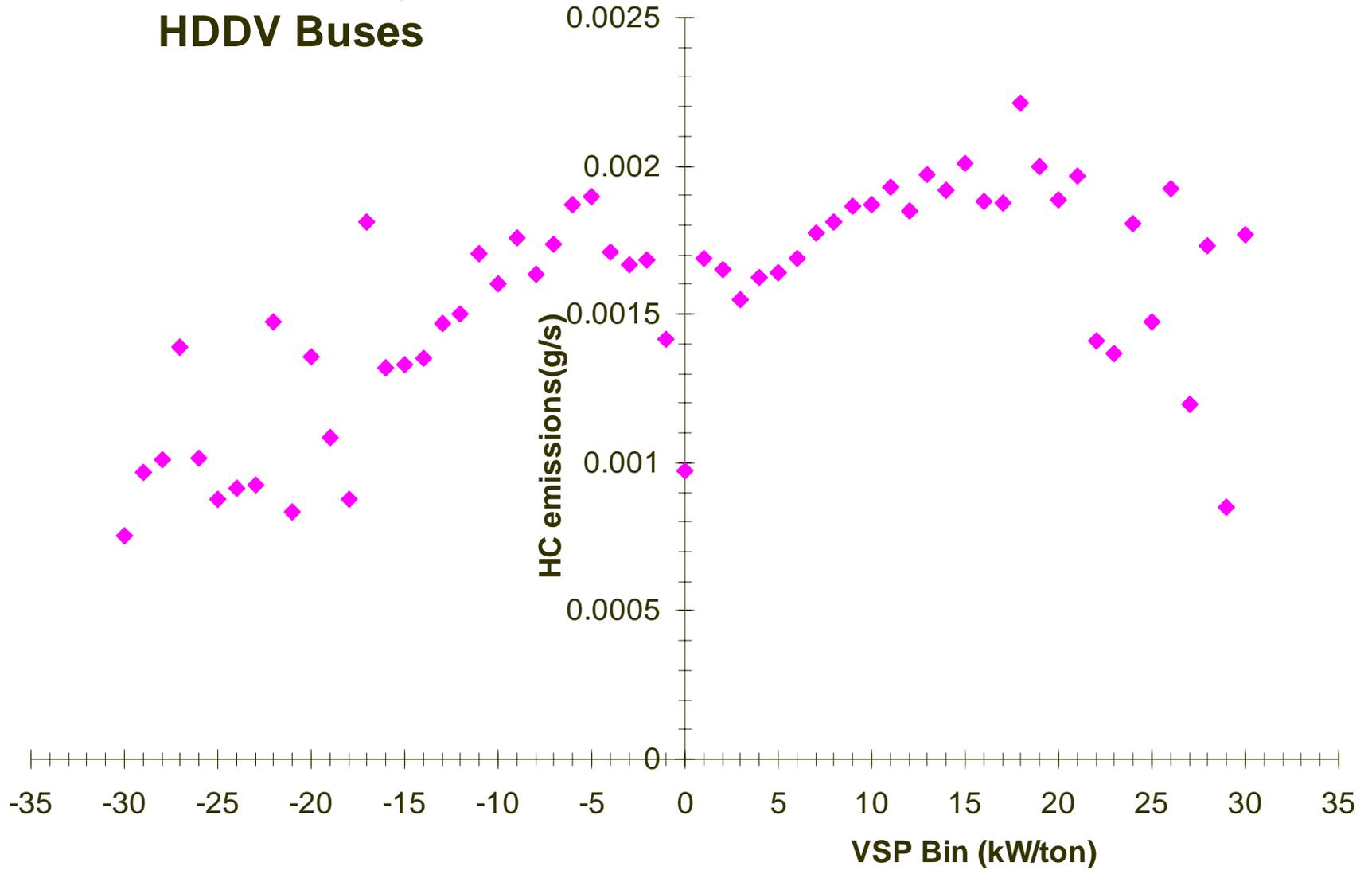
0.42 = drag term coefficient

# CO2 Emission Rate By VSP Bin HDDV Buses

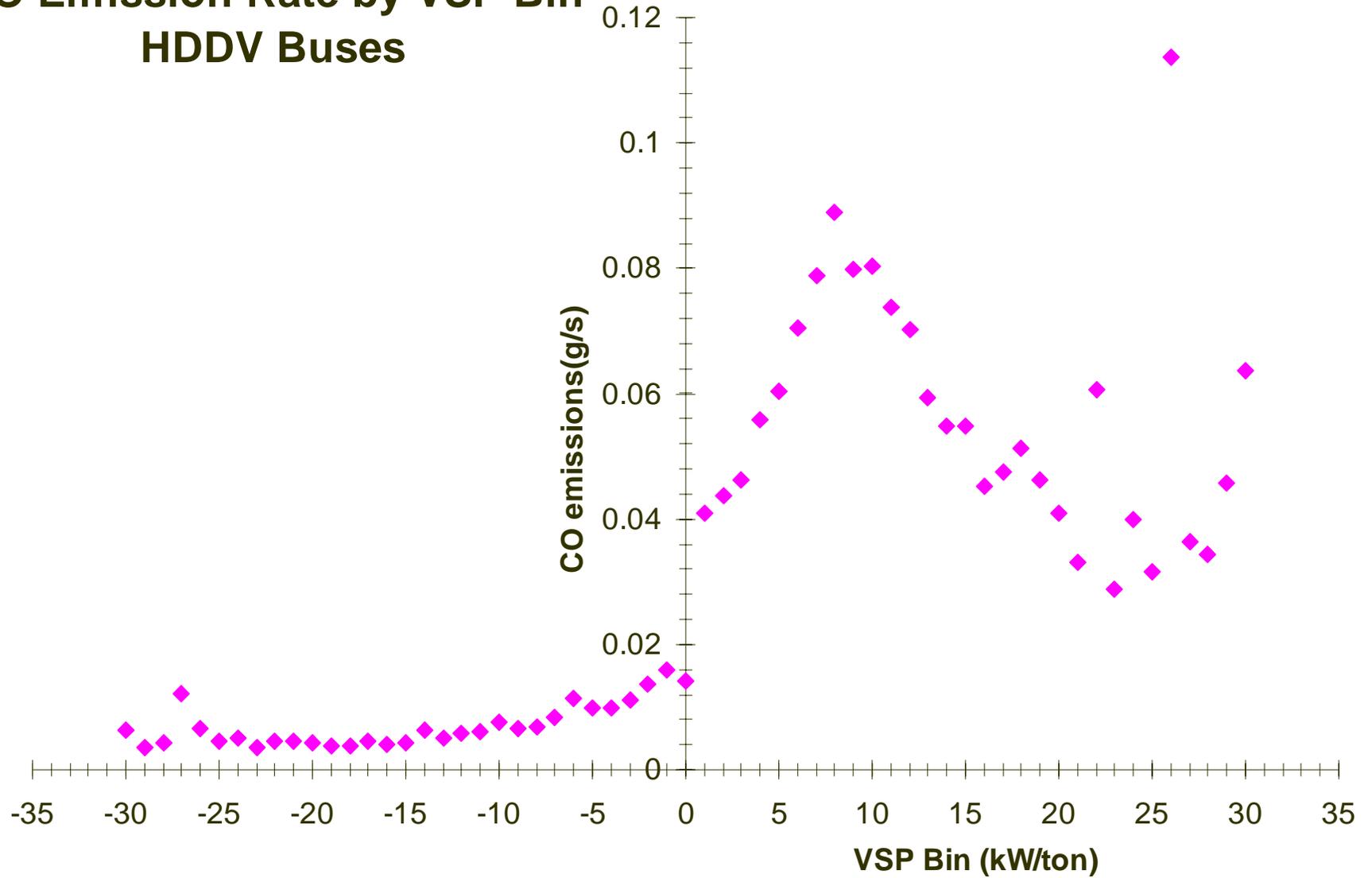


# HC Emission Rate by VSP Bin

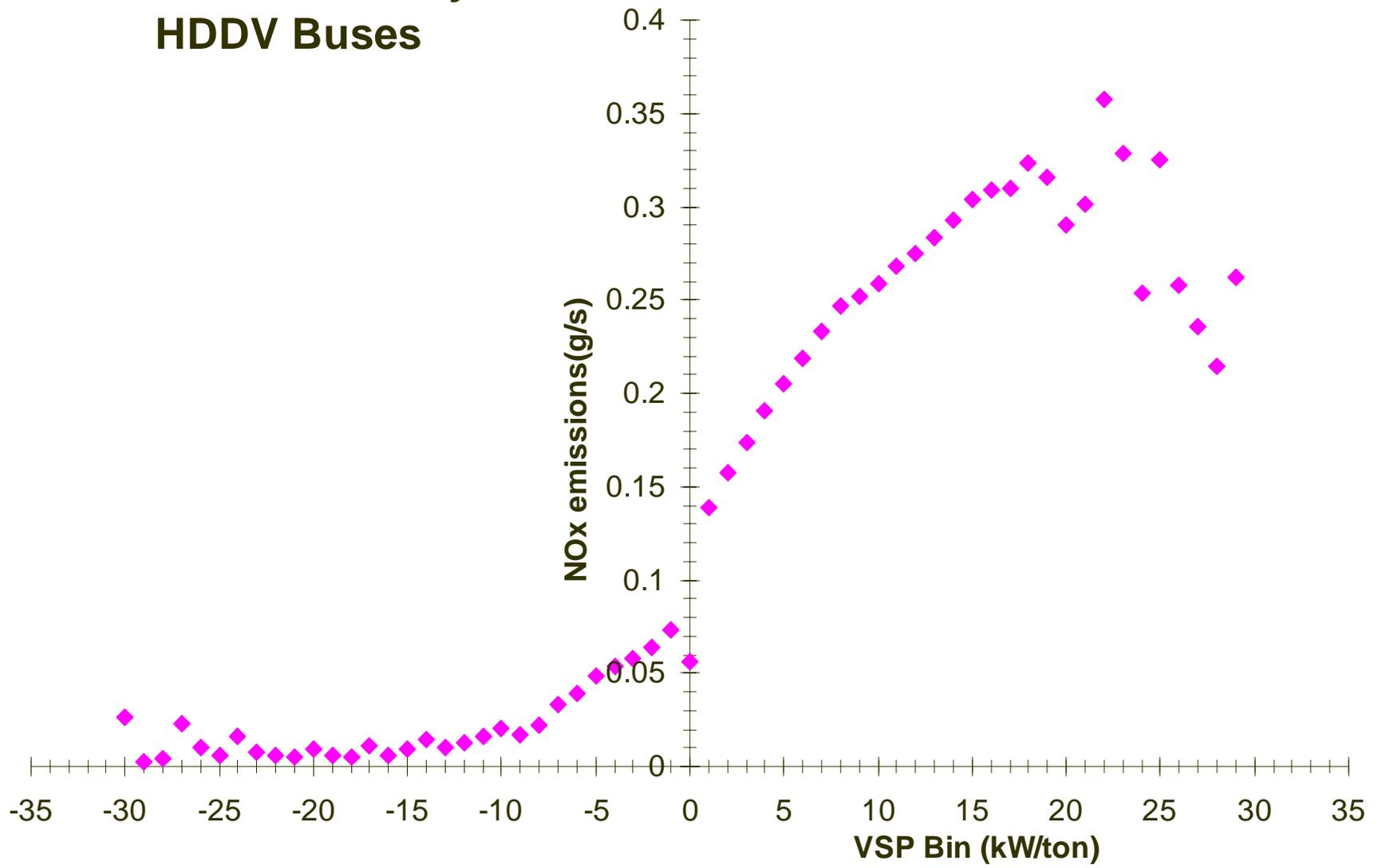
## HDDV Buses



# CO Emission Rate by VSP Bin HDDV Buses



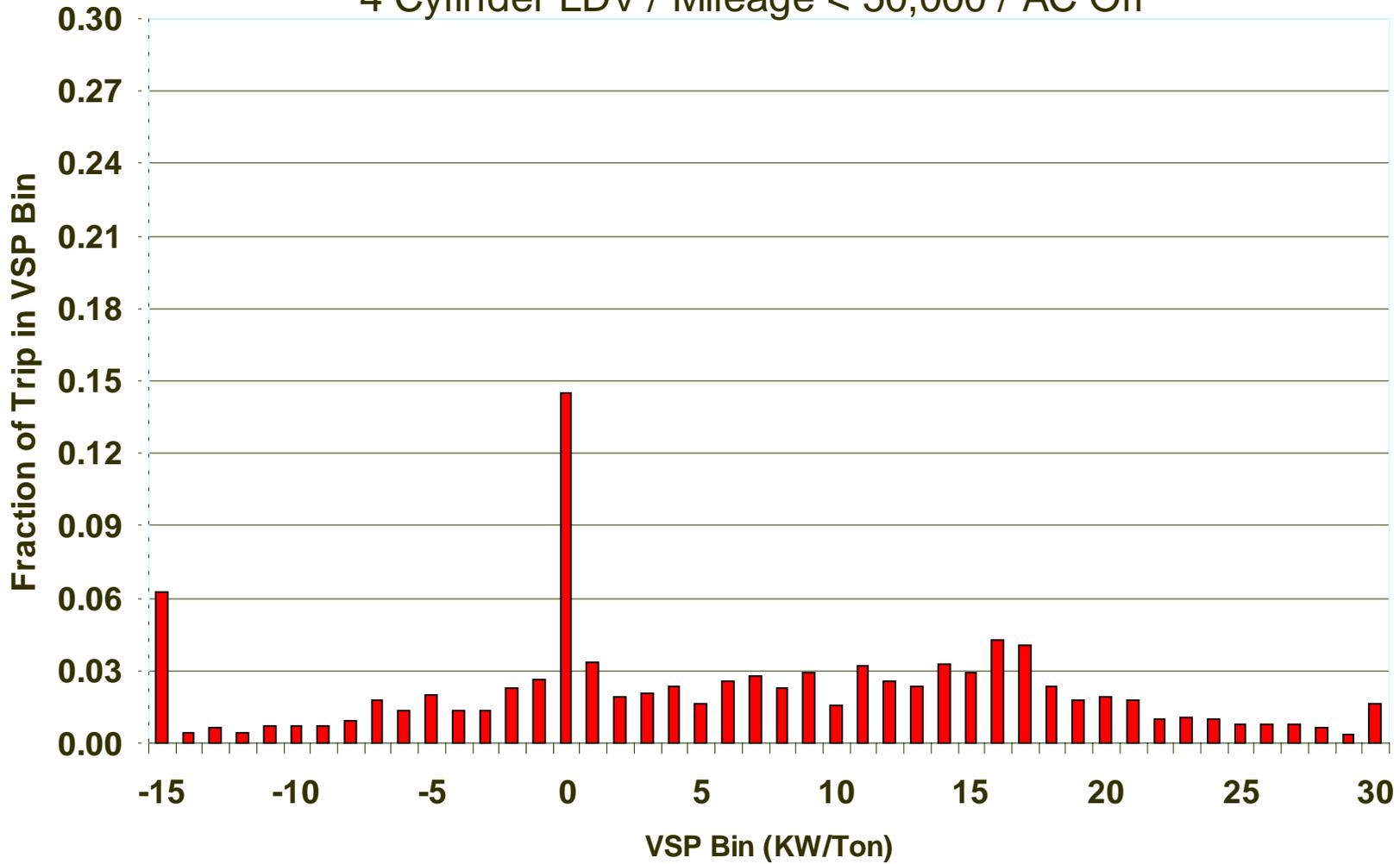
# NOx Emission Rate by VSP HDDV Buses



# VSP Bin Frequency Distribution

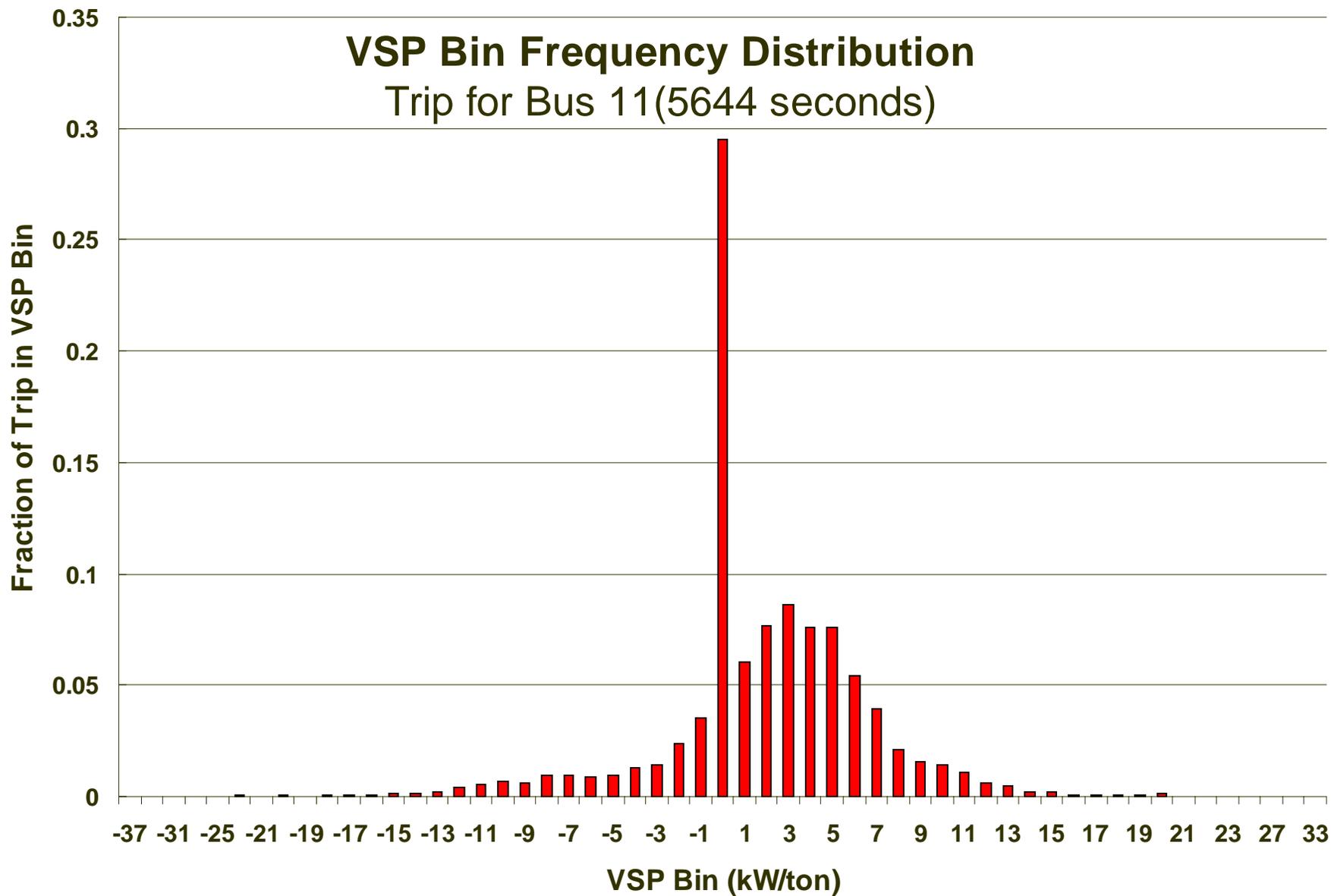
Trip RAK416TR\_4 (1105 Seconds)

4 Cylinder LDV / Mileage < 50,000 / AC Off



# VSP Bin Frequency Distribution

Trip for Bus 11 (5644 seconds)



# Predicted Emissions

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- Predicted trip emissions  
= VSP distribution for a trip  
x (emission rates by VSP bins)  
x (total trip time)

# Nonroad

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- Excluded records where
  - Engine speed  $\leq 0$
  - Exhaust flow  $\leq 0$
  - Pollutant concentration  $\leq 0$
- Used straight averages of instantaneous emission rates